DEVELOPMENT OF AN ULTRA-COMPACT EXPLOSIVELY DRIVEN MAGNETIC FLUX COMPRESSION GENERATOR SYSTEM

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Abstract

Explosively driven magnetic flux compression generators (MFCG) are effective high current, compact, disposable pulsed power supplies [1]. A common type of MFCG in use is a helical generator, HFCG, because it can provide very high current gain in a compact form. Successful implementation of a HFCG as a pulsed power source requires several peripheral systems including a seed current source and a high current switching mechanism. Additionally, for driving higher impedance loads, a power conditioning system is required to convert the high current, low voltage HFCG output into a more suitable voltage. HEM Technologies' currently developed system utilizes an ultra compact, seed source previously developed by HEM Technologies [2]. An explosively driven closing switch provides both the switching action and acts as a delay generator to allow for the current rise in the HFCG. The output of the HFCG is conditioned via an exploding fuse wire and spark gap pair to convert the high current output to high voltage. HEM Technologies has performed extensive modification and testing of the end-to-end system. The current and energy conversion will be presented along with typical output voltages using different fusing techniques.

I. INTRODUCTION

The generator is designed to be a complete end to end system while remaining compact and self sufficient. To this end, every stage of the device is explosively linked. This means only a single detonator is need to activate the entire system. The detonation chain initially closes an explosively driven closing switch, connecting the seed current source to the generator. An explosive delay line allows sufficient time for the current to rise in the generator before the crowbar action occurs. The generator then compresses the established magnetic flux and opens the explosive fuse wire causing a rise in the output voltage which is then connected to the high impedance load through a spark gap. The complete system, see Fig. 1, is divided into three major parts, the seed source, the HFCG, and the output conditioning apparatus.

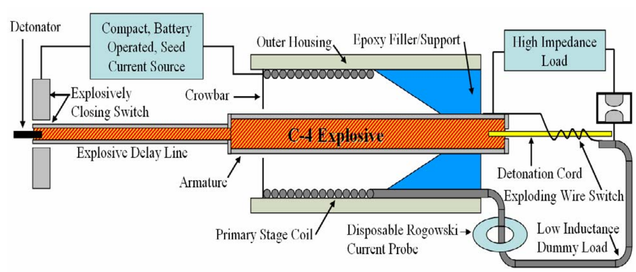

Figure 1. Schematic of the complete generator system.

II. EXPERIMENTAL SETUP

A. Seed Current Source

Most HFCG rely on an external seed current source to establish the initial magnetic field in the coil. This is obviously undesirable in an ultra compact, warhead housed system. Using a 10 J, 1 kV, compact, battery operated seed current generator previously developed by HEM Technologies, see Fig. 2, this external dependence is limited. This arrangement maximizes the source energy density compared to other similar compact sources. The seed current generator is capable of providing in excess of 1 kA to the HFCG [3]. The seed current source can be

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14. ABSTRACT
Explosively driven magnetic flux compression generators (MFCG) are effective high current, compact, disposable pulsed power supplies [1]. A common type of MFCG in use is a helical generator, HFCG, because it can provide very high current gain in a compact form. Successful implementation of a HFCG as a pulsed power source requires several peripheral systems including a seed current source and a high current switching mechanism. Additionally, for driving higher impedance loads, a power conditioning system is required to convert the high current, low voltage HFCG output into a more suitable voltage. HEM Technologies currently developed system utilizes an ultra compact, seed source previously developed by HEM Technologies [2]. An explosively driven closing switch provides both the switching action and acts as a delay generator to allow for the current rise in the HFCG. The output of the HFCG is conditioned via an exploding fuse wire and spark gap pair to convert the high current output to high voltage. HEM Technologies has performed extensive modification and testing of the end-to-end system. The current and energy conversion will be presented along with typical output voltages using different fusing techniques.

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fully charged in under a second making it ideal for fast operational applications.

Figure 2. Image of 10 J energy source, previously developed by HEM Technologies.

B. HFCG

The inductance of the HFCG, ~10µH, is chosen to maximize both the current provided by the seed source and the period over which maximum current is applied to the generator. This allows for some "jitter" in the time it take for the crowbar to be engaged, which ideally happens at maximum current. The generator is a single stage, 16 turn HFCG attached to a low impedance dummy load through the exploding wire switch. The armature radius to coil radius ratio is maintained at ~2 for maximum gain [1]. The dummy load is also designed for low inductance, 1-3 µH, to maximize the current gain of the system.

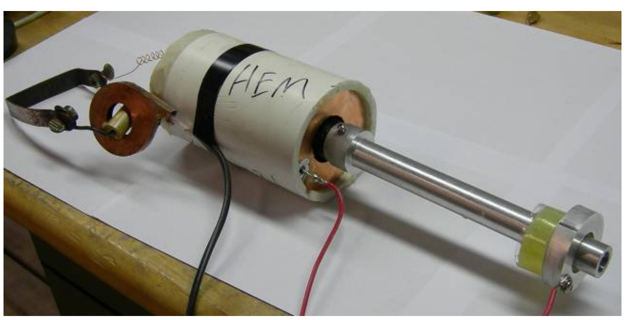

Figure 3. Image of complete system including explosively closing switch, delay line, HFCG, fuse wire (without detcord), low inductance load, and current sensor. Seed current generator, connected via the red wires, is omitted.

C. Power Conditioning, Initial Testing

Currently available exploding fuse wire opening switches rely on ohmic heating and vaporization of the wire by the current. In addition to energy lost to vaporizing the wires, a quenching medium is typically needed to prevent restrikes through the cloud of vaporized metal that is left behind after the switching event. The media is usually silicon sand. The sand is bulky and must be contained which is not conducive to compact systems. Timing is another issue with exploding fuse wires, as the time to fuse is highly dependent on the rate that energy is deposited in the wire. Both of these limitations make current exploding fuse wire switches less that ideal for a low energy, high reliability system.

The exploding wire switch proposed utilizes detonation cord, detcord, to destroy the wire and open the switch. Because the switching action is less dependent on the energy imparted on the wire and more on the speed of detonation, switching time and jitter are more consistent over a wide range of output energies. In addition, quenching media is not needed as it would only slow the rate of expansion of the metal vapor cloud. Finally, the switch can be integrated into the detonation sequence to further reduce the complexity of the system.

Initial test were performed at low currents, ~1kA, to determine the best physical arrangement for achieving the fastest switch time, which would lead to the highest voltage output. To close the circuit, a simple explosive switch was designed in which the detcord lies over the top of a thumb tack, driving it through a top copper sheet (~10mil thick), a layer of insulating tape, and into a bottom copper sheet completing the connection. The remaining length of the detcord acts as a timer to allow the current to rise prior to "opening" the fuse. The switch was highly reliable with no bounce and only a 1-2µs jitter.

D. Power Conditioning, High Current Testing

In order to perfect the high current exploding wire opening switch, which is normally attached to the HFCG, an iterative approach is utilized. However, given the time and cost requirement of constructing the HFCG driver, a substitute source is required to mimic the output of the HFCG. This has been accomplished by coupling the seed current generator to a larger capacitor, see Fig. 4. This setup is capable of repeatedly delivering up to 10kA to the load inductor and fuse under test. The same explosively closing switch and detcord timing used in the low current setup is employed. The system can be seen in Fig. 5 below.

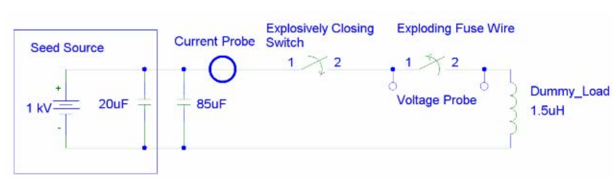

Figure 4. Schematic of HFCG simulator, including the extra capacitor, current/voltage sensors, explosively closing switch, fuse wire under test, and low inductance load.

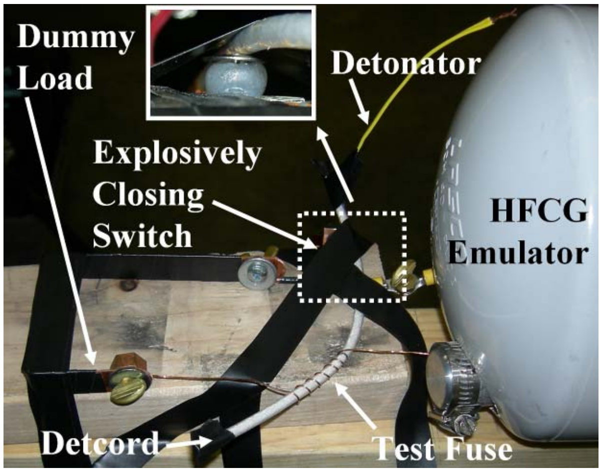

Figure 5. Image of complete system including HFCG simulator, explosively closing switch, detcord delay line, fuse wire under test, and low inductance load.

III. RESULTS

A. HFCG

The HFCG section of the device, consisting of the seed current generator, explosively driven closing switch, delay line, helical generator, and low impedance load has been developed and tested to ensure a desirable output. The construction method has been carefully documented to ensure consistency from generator to generator. Even with these precautions some variation from shot to shot is to be expected. The results of a number of tests can be seen Fig. 6 thru Fig. 8. The typical current gain is a factor of 10 corresponding to a typical output current of 10kA, with the output current ranging from 5kA to 30kA in the extreme cases. Given the low inductance load, the energy gain is between 1 and 15, or between 5J to 78J.

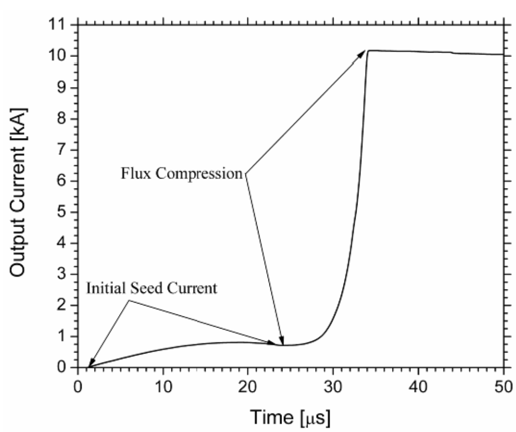

Figure 6. Current output from typical HFCG seeded with 1kA. The device achieved a current gain of ~14 and an energy gain of ~3.

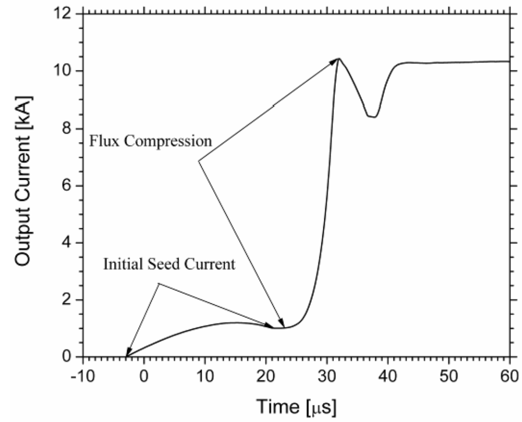

Figure 7. Current output from typical HFCG seeded with 1kA. The device achieved a current gain of ~10 and an energy gain of ~1.5.

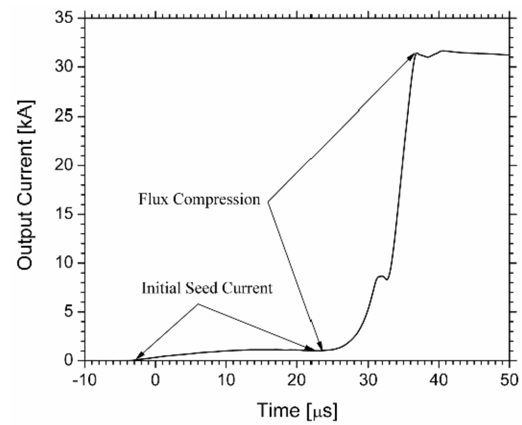

Figure 8. Current output from an atypical HFCG seeded with 1kA. The device achieved a current gain of ~31 and an energy gain of ~15.

B. Power Conditioning, Low Current Testing

Initial fuse testing was conducted under low current (<1kA) conditions. Several explosive/fuse configurations, seen in Fig. 9, were tested and the corresponding output voltages are shown in Fig. 10. The fastest configuration, resulting in the highest output voltage, which involved wrapping the fuse wire around detcord stripped to its inner jacket, resulted in a rise time of about 1 μs and increased the output voltage by an order of magnitude. This was sufficient for a proof of principle for voltage amplification.

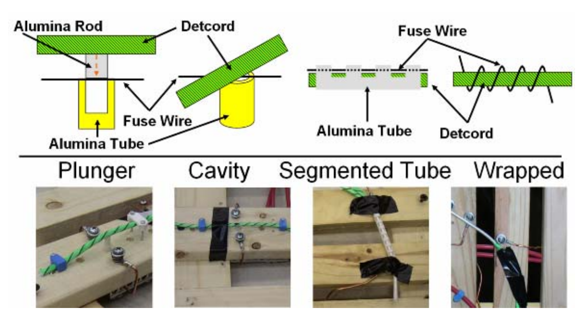

Figure 9. Several explosive/fuse configurations tested.

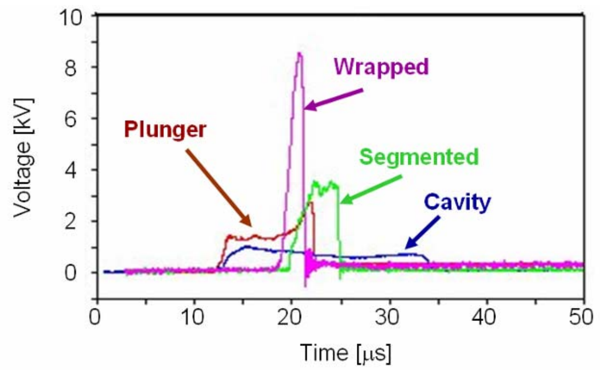

Figure 10. Voltage output of several explosive/fuse configurations seeded with ~1kA source current.

C. Power Conditioning, High Current Testing

Several explosive fusing methods are explored starting with the best performer from the low current testing; the results for the best designs are shown in Fig. 11 and 12 below. While the opening time appear to be sufficiently fast, re-strikes becomes an issue at high currents. More design iterations are needed to optimize the switching setup for higher currents.

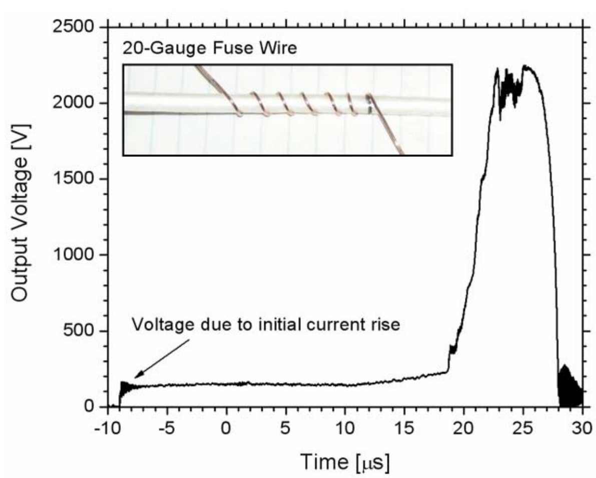

Figure 11. Voltage output of 20-gauge copper wire fuse, seeded with ~10kA source current. Initial voltage rise is due to initial current flow across the load inductor.

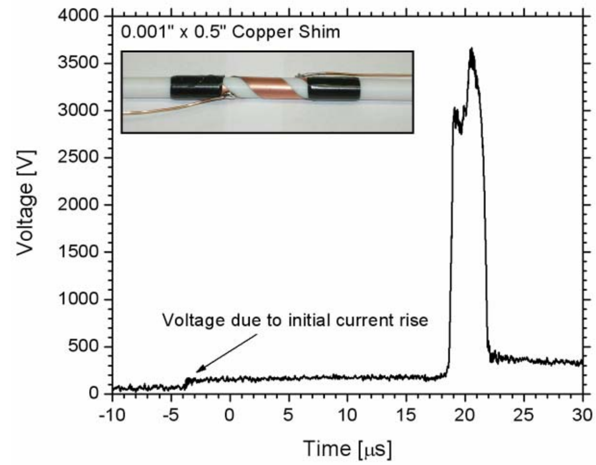

Figure 12. Voltage output of 1mil thick copper shim stock fuse, seeded with ~10kA source current. Initial voltage rise is due to initial current flow across the load inductor.

IV. CONCLUSION AND FUTURE WORK

By explosively linking the initiation process, seed current closing switch, delay to crowbar, and fuse opening the HFCG can be made very reliable. Current outputs of up to 30kA can be achieve by the compact 10μH HFCG, with energy gains from 1 to 15. The explosively triggered fuse can provide the necessary opening times, however re-strike issues must be mitigated.

Future plans include continuing to test and improve in the HFCG. To this end, the HFCG's performance into higher inductance loads will be tested. Additional improvement could include adding multiple stages to increase gain. The explosively triggered fuse will also undergo more iterative testing and improvement. This will primarily consist of modifying the physical layout to mitigate re-strike.

V. REFERENCES

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